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(54) IMPROVEMENTS IN OR RELATING TO OPTICAL LENSES

(71) We, ROBERT BOSCH GMBH, a German Company, of Postfach 50, 7 Stuttgart 1, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a lens with controllable focal length.

A lens having rapidly variable focal length is required, for example, when it is required to concentrate a laser beam onto a plane to form on the plane a focal point (burning spot) of the greatest possible energy density and the greatest possible time-constancy of that energy density. Since the focal point in laser beams can have a diameter of only a small number of times the wavelength, the smallest alteration of the distance between the focusing lens and the plane, such as results from extraneous vibrations has a considerable influence on the energy density and the size of the focal point. It would be possible with a controllable lens of small inertia or reaction time to control the focal length by means of a controlling parameter derived from the vibration, in such a way that the focus of the lens always coincides with the plane, thereby maintaining a constant energy density in the focal point. Other applications could be, for instance, carrying out a light modulation or obtaining a contantly sharp representation of an object in rapid motion, on a plane.

Optical lens systems with variable focal length are already known under the names: "Varioptik" or "Gummilinse"; these are systems which have a plurality of glass lenses relatively displacable to alter the focal length of the system. This displacement is normally effected by means of a small electric motor. Such a system is useless for the applications described above because the mechanical inertia in displacements of this kind is far too large.

A single lens element with variable focal length is known in which at least one boundary surface consists of an elastic material and the refracting medium of which surface is a fluid, fluid pressure being manually variable by means of a rubber bulb fixed on the end of a tube. This construction, however, is also subject to high inertia. The invention seeks to provide an optical lens whose focal length is alterable by means of a control signal with the greatest possible absence of inertia, for example, a relation time of one millisecond or less.

According to the present invention, there is provided an optical lens with electrically controllable focal length, comprising a housing having two openings constituting an optical path through the housing, at least one of the openings being covered by a transparent membrane, the housing containing a fluid and a piezoelectric element in contact with the fluid, the piezoelectric element being arranged such that, on being subjected to a change in voltage, it changes in dimension so that the fluid pressure exerted on the membrane is changed and the radius of curvature of the membrane is thereby altered.

In a preferred embodiment, the piezoelectric element is connected to an optically transparent body such as a glass plate, which is located in the optical path adjacent the membrane and transmits the variations in dimensions of the piezoelectric element to the fluid near the membrane. Preferably, the piezoelectric element is formed as a hollow cylinder and is metallised on its inner and outer surface for the application thereto of the control voltage.

The focal length of an optical lens of this construction can be varied in a very brief time

interval and in quick succession by the application of an a.c. voltage to the electrodes of the piezoelectric element so that the disturbances due to shaking, having a frequency of 1kHz or greater, can be compensated by an a.c. voltage potential of corresponding frequency and amplitude. A further useful development of the invention is to provide the housing with a further opening in which a displaceable piston is located, by displacement of which an initial pressure can be set in the lens for setting the initial curvature of the membrane. If this piston is equipped with a fine screw thread, the fluid pressure in the lens can be very accurately set. The cylindrical piezoelectric body exhibits dimensional change in a radial direction.

The material for the diaphragm can consist of an elastic and transparent material, such as a polyester. With a thickness of about 100 mμ a membrane of this kind is sufficiently elastic to follow the pressure variations of the fluid virtually without inertia.

In the manufacture of a membrane of this kind there is often produced a certain double refraction because of overstretching in a particular direction. This double refraction can be used in certain cases to achieve simultaneously the effect, with the variable lens, of a quarter-wave plate which is sometimes necessary in the optical path; this can be desirable for influencing the state of polarisation of the light beams. Silicone oil has proved a suitable fluid for filling the lens. The refractive index of the fluid or, as the case may be, of the above-mentioned transparent glass plate, should be adjusted (or fixed) so that both media have the same refractive index.

The invention is further described by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows in section the mechanical construction of a lens according to the invention, and

Figure 2 shows an example of application of a lens according to the invention.

In Figure 1, a cylindrical housing 1 has two openings 2 and 3 for the through passage of a beam of light. In the opening 3 a transparent elastic membrane 5 is stretched by two rings 4 and 4a. A hollow cylinder of piezoelectric material 6, e.g. a lead zirconium titanate ceramic, is located in the housing and surrounds the optical path and is closed at its end adjacent the membrane 5 by a transparent glass plate 7. Both the inner and outer sides of the piezoelectric cylinder are metallised, the metallising being equipped with electrical leads (not shown). The space bounded by the inner wall of the housing 1, the outer wall of the piezo-ceramic cylinder 6 and the side of the glass plate 7 adjacent the membrane 5 is completely filled with a fluid such as silicone oil. A bore 8 is formed in the wall of the housing 1 and receives a pressure screw 9 equipped with a piston 10. By means of the pressure screw 9 and the piston 10, the fluid pressure can be finely adjusted. If the pressure of the fluid is raised, the unsupported part of the membrane 5 bulges outwardly, while when the pressure is lowered, the curvature of the membrane 5 is reduced, so that the refracting power of the lens is altered. If a potential is applied to the piezo-ceramic cylinder 6, the diameter and length thereof is either increased or decreased according to the polarity of the applied potential. The alteration of the refractive power of the lens is approximately proportional to the applied potential. The maximum frequency of the change in refractive power is limited by the excitation of resonant vibrations in the elastic membrane 5. In measuring the frequency characteristics of a lens of this kind it was discovered that the amplitude of refractive power variation is virtually constant up to about 3×10^3 kHz, and that only above this frequency do natural vibrations of the membrane become noticeable. It is, of course, possible to increase the natural vibration limit by the choice of a different membrane material, a different membrane thickness or a different membrane diameter. Since extraneous vibrations which reach optical apparatus through a supporting surface such as a table surface mostly having a frequency below 1,000 Hz, an efficient compensation for disturbances produced by extraneous vibration can be achieved with a lens according to the invention.

The piezoelectric controlling element of the variable lens possesses an extremely small inertia factor, since the mass of the mobile central portion of the membrane is very small. Figure 2 shows schematically and partly in the form of a circuit diagram a regulating device with a variable lens. In Fig. 2 a light beam 11 of small divergence, is generated by a laser (not shown) and is focussed upon the surface of record foil 13 by means of focussing lens 12. The record foil 13 is advantageously a tape made of plastics material which is provided with a metallic coating. When the focal point formed by the lens 12 strikes the metallic coating, the coating is burnt away so that a transparent track is produced as the tape rolls past.

The movement of the record foil 13 can be intermittent, so that the track is formed by a plurality of transparent spots following each other in sequence to constitute a signal.

The surface of the record foil can become displaced out of the focal plane of the lens 12 as a result of variations in thickness of the record foil and also as a result of mechanical shocks and changes in temperature, so that the energy density of the focal point of the laser beam is reduced and no burning of the metallic layer takes place. To avoid this, a beam divider in the form of a semi-transparent mirror 14, is provided in the

beam 11 which causes a portion of the light reflected back by the focal point on the record foil 13 to be diverted to form a control beam 11a. The control beam 11a passes through a further semi-transparent mirror 18, a cylindrical lens 15 and a slit in a screen 16 and then enters a photocell 17. The portion of the control beam reflected by the beam divider 18 enters a second photo-cell 19. A voltage divider 20 is provided between the photo-cell 19 and earth, a tapping of which voltage divider can be set so that the output voltage of the photo-cell 19 is equal to the output voltage of the photo-cell 17, when the focal point of the laser beam 11 lies exactly upon the surface of the record foil 13. Approximate equality of the output voltage is achieved by appropriate choice of the reflection characteristics of the beam divider 18. The output voltages of the photo-cells 17 and 19 are fed to the input terminals of a differential amplifier 21, which compares these voltages and produces at its output a differential voltage which can be positive or negative depending on the direction of displacement of the surface of the record foil 13.

The output voltage of the differential amplifier 21 is then fed to a power amplifier 22, which supplies an output voltage up to ± 100 volts. This output voltage is connected to the input of a controllable lens 23 constructed according to the invention, such that the refractive power and focal length of the lens is varied in conformity with the alterations of the amplified differential voltage. The alterations in the refractive power of the lens 23 cause a displacement Δz of the focal point of the lens 12 in such a direction that the displacement of the record foil 13, which has given rise to the differential voltage is compensated, and the focal point is retained on the surface of the record foil 13. Depending on whether the record foil 13 was displaced in a direction towards the lens 12 or away from it, the voltage applied to the lens 22 is positive or negative and the refracting power of the said lens is increased or reduced accordingly.

In one practical example which was carried out, an alteration in refractive power was obtained of a value given by:

$$\frac{\Delta f}{f^2} = 2.6 \times 10^{-3} \text{cm}^{-1}$$

with an alteration of the control voltage of 100 volts, independently of the refractive power which results at a control voltage of 0 volts.

The optical system with the lens 12 and the lens 23 offers a range of adjustment from ± 30 mμ with a focal length of 16 mm. The system demands focussing with an accuracy of 1 or 2 mμ, so that the use of a regulable lens according to the invention can make a considerable contribution towards reducing the mechanical requirements of the system.

WHAT WE CLAIM IS:—

1. An optical lens with electrically controllable focal length, comprising a housing having two openings constituting an optical path through the housing, at least one of the openings being covered by a transparent membrane, the housing containing a fluid and a piezoelectric element in contact with the fluid, the piezoelectric element being arranged such that, on being subjected to a change in voltage, it changes in dimension so that the fluid pressure exerted on the membrane is changed and the radius of curvature of the membrane is thereby altered.

2. A lens as claimed in claim 1 in which the piezoelectric element is connected to a solid, optically transparent body, lying in the optical path immediately adjacent the membrane to transmit dimensional change of the piezoelectric element to the fluid volume near the membrane.

3. A lens as claimed in claim 1 or claim 2 in which the housing also consists of piezoelectric material and is metallised on its inner and outer sides to accept a control voltage.

4. A lens as claimed in claim 2 or claim 3 in which the housing is of substantially cylindrical form having the openings at its ends, the piezoelectric element likewise being cylindrical and encompassing the opening, remote from the membrane, the solid body being a transparent plate fixed onto the end of the cylindrical piezoelectric element adjacent the opening which is closed by the membrane.

5. A lens as claimed in claim 4 in which the cylindrical piezoelectric element is radially polarised and metallised on its inner and outer sides and adapted to be connected to the opposite terminals of a source of control voltage.

6. A lens as claimed in any preceding claim in which the housing has a bore in which a displaceable piston is located, displacement of the piston permitting initial setting of fluid pressure and membrane curvature.

7. A lens as claimed in claim 6 in which the piston is equipped with a screw thread such that rotation of the piston causes longitudinal displacement thereof.

8. A lens as claimed in any preceding claim in which the membrane is formed of a polyester.

9. A lens as claimed in any preceding claim in which the thickness of the membrane is about 100 mμ and the fluid is a silicone oil.

10. A lens as claimed in claim 2 in which the refractive index of the solid body and of the fluid are substantially equal.

11. A lens as claimed in any preceding claim in which the membrane has doubly refracting properties and has such a thickness that the phase difference between the two refracted

components of the beam corresponds to one quarter of the wavelength of the light when the beam is normal to the lens.

12. A regulating arrangement for regulating the position of the focal point of an optical lens system with respect to a recording surface in a recording device in which a light beam focussed by the said system records a track on the recording surface which is moved relative to the light beam, in which the regulating arrangement comprises a beam splitter, a device for influencing the distance of the focal point from the recording surface by electrical signals, a photocell, and a screening device, and in which the beam splitter is arranged so that a part of the light beam reflected by the recording surface, and returning through the main optical system, is detected by the photocell, the screening device having focussing means and a screen which allows a variable portion of the deviated light to strike the photocell in dependence upon the position of the main focal point relative to the recording surface, and the signal voltage taken from the protocell being arranged to control the device influencing the focal distance, said device for influencing the distance of the focal point from the recording carrier including an optical lens as claimed in any preceding claim.

13. An optical lens with electrically controllable focal length, constructed and adapted to operate substantially as hereinbefore described with reference to and as illustrated in Fig. 1 of the accompanying drawings.

14. A regulating arrangement constructed and arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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Fig.1

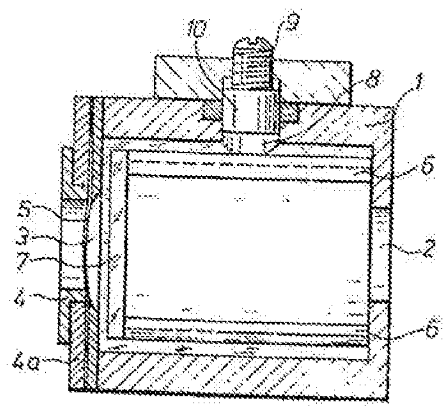

Fig. 2